# Section 3.0 Best Management Practices

This section the use of sedimentation ponds in arid and semiarid regions, presents the theory behind BMP implementation, presents modeling techniques that aid in BMP design and prediction of BMP effectiveness, and describes the site-specific sediment control measures and techniques that may be employed.

## 3.1 Sediment

In arid and semiarid watersheds, sediment can be defined as all material transported by surface water drainage, including dissolved, total suspended, and settleable solids and bedload. In this environment, climate, topography, soil, vegetation and hydrologic components all combine to form a hydrologic balance that is naturally sediment rich. The dynamic fluvial systems in these watersheds depend upon a continuous source and flow of sediment to maintain the existing natural sediment balance. Consideration of the importance of sediment balance in this region is as critical as the availability of water.

## 3.2 Sedimentation Pond Use and Impacts in Arid and Semiarid Regions

The numeric effluent limitations established at 40 CFR part 434 for discharges in mining and non-process areas were based upon the treatment capabilities of sedimentation ponds, with nominal consideration of the impacts on the environment in the Western Region. Implementation of sedimentation ponds to meet these numeric effluent limitations has taken precedence over SMCRA's requirement to minimize possible impacts to the hydrologic balance.

Reliance on sedimentation ponds as the primary technology to control sediment and to achieve effluent limitations has resulted in the construction and operation of a significant number of ponds at coal mining and reclamation operations in the arid and semiarid west (Western Coal Mining Work Group, 1999a). While sedimentation ponds may be capable of achieving the sediment concentration reductions necessary to meet EPA discharge limitations, the net effect of achieving those reductions can represent a disruption of the hydrologic balance (Doehring, 1985). In summary, sedimentation pond use in arid and semiarid western regions can:

- Require significant additional surface disturbance;
- Result in environmental harm through the disruption of hydrologic balance;
- Adversely affect valuable riparian or aquatic communities; and
- Create contention during the administration of basin water rights.

### *3.2.1 Surface Disturbance*

Due to topographic constraints, lease boundary constraints, and a high occurrence of ephemeral and intermittent drainage within western surface coal mine permit areas, sedimentation ponds are often constructed within natural drainage ways that convey surface runoff from both disturbed and undisturbed areas (Simons. Li & Associates, 1982). The larger volumes of runoff and sediment from these combined areas must be detained long enough to achieve CWA effluent limitations, requiring the construction of larger ponds and the disturbance of larger surface areas. With the establishment of the SS limits at 40 CFR part 434, sedimentation ponds were upgraded through expansion and new ponds were designed to increase detention times by providing larger volume capacity.

As an example of the significant impact of sedimentation ponds in arid and semiarid environments, the Western Coal Mining Work Group provided the following information from four coal mining sites. A breakdown of the number of sedimentation ponds being used, area disturbance and acres of watershed drainage at each mine site is presented in Table 3a. The Pittsburg & Midway Coal Mining Company's McKinley Mine in New Mexico uses 79 ponds, BHP Coal Company's Navajo Mine in New Mexico uses 30 sedimentation ponds, and Pacificorp's Dave Johnston Mine in Wyoming operates 14 sedimentation ponds. There are currently 149 sedimentation ponds with the potential to impound 4,500 acre-feet of water at the Peabody Western Coal Company’s Black Mesa Mine in Arizona. The total area of disturbance from the implementation of these sedimentation ponds is approximately 887 acres, resulting in an average of 3.3 surface acres disturbed per sedimentation pond.

**Table 3a: Area Disturbance and Watershed Drainage of Sedimentation Ponds at Four Western Mine Operations (Western Coal Mining Work Group, 1999a)**

| Mine Site | Number Of Sedimentation Ponds | Acres Disturbed | Watershed Acres Draining Into Ponds |
|---|---|---|---|
| Black Mesa Mine | 149 | 540 | 45,720 |
| McKinley Mine | 79 | 211 | 7,050 |
| Navajo Mine | 30 | 100 | 4,331 |
| Dave Johnston Mine | 14 | 36 | 4,567 |
| **Total** | **272** | **887** | **61,668** |

In contrast, Bridger Coal Company's operation in southern Wyoming (Section 5, Case Study 2) has successfully applied alternative sediment control measures for over 5,260 acres with only 3.9 acres of additional disturbance. If sedimentation ponds had been implemented at this site, the extensive surface area affected by mining and the drainage density would require operation of roughly 200 sedimentation ponds disturbing roughly 660 acres to control all runoff during the life of the mine.

### *3.2.2 Water Impoundment*

Sediment control historically has focused on the capture of surface water runoff in sedimentation ponds located on the bottom periphery of disturbance areas (Western Coal Mining Work Group, 1999a). Surface water runoff contained in a sedimentation pond may evaporate, and therefore, may not be available for downstream or consumptive uses.

Sedimentation ponds typically are sized to treat or contain the combined sediment and runoff volume resulting from a 10-year, 24-hour storm event (Appendix C: 19 NMAC 8.2.20.2014, 1997). A result of the implementation of this design in arid and semiarid regions is that, for the majority of storm events, downstream channel flow is either eliminated or significantly attenuated. Loss of runoff water, through the storage of runoff in sedimentation ponds, evapotranspiration, and localized infiltration, can significantly affect the local hydrologic balance, downstream resources, ground water hydrology, and the spatial pattern of alluvial recharge (Doehring, 1985).

Sedimentation ponds have the potential in some cases to disrupt hydrologic balances and impact associated environmental resources. Downstream surface runoff volumes may be drastically reduced or completely eliminated if non-discharging structures are used for sediment treatment, and typically are reduced 80 to 90 percent below pre-mining flow rates when discharging ponds are used for water treatment (Western Coal Mining Work Group, 1999a). Disruption of flow volume at this magnitude is a concern in arid and semiarid regions. Avoiding or minimizing disruption to stream flow is also a "key program objective and activity to be undertaken in the next decade" by the Water Quality Criteria And Standards Plan-Priorities for the Future (U.S. EPA, 1998).

The National Mining Association employed computer modeling techniques to predict BMP and sedimentation pond performance and resulting sediment yield at non-process areas for three representative model mines in the arid and semiarid west (Western Coal Mining Work Group, 1999c). Details of these prediction studies are presented in Section 5, Case Studies 1, 2, and 3, and in Appendix D of this document. In a model of the Desert Southwest Coal Region, the maximum storage capacity of sedimentation ponds used for the model was 60 acre-feet. This means that out of 73 acre-feet of runoff (predicted from a 10-year, 24-hour precipitation event for the reclaimed and adjacent undisturbed areas), only about 13 acre-feet would pass through the sedimentation pond. The model assumed an additional 30 acre-feet of water would be released from the pond system to the downstream watershed by automatic dewatering over an 8-day period. Thus, the runoff volume from the storm event that would pass through the pond and be available to the down-drainage hydrologic system would be only 41 percent of the total runoff volume produced by the storm. In addition, the peak flow was predicted to be 45 cfs when sedimentation ponds are implemented and 602 cfs when alternative sediment control BMPs are implemented. This peak flow compares to 679 cfs predicted to occur naturally under undisturbed conditions. Similar model results for the Intermountain and Northern Plains coal regions resulted in a 96-97% reduction in naturally occurring peak flow when sedimentation ponds are used to meet numeric limits, compared to a 33-38% reduction in naturally occurring peak flow when using alternate sediment controls. The result of these models demonstrate that the use of alternate sediment control systems increases the amount of precipitation runoff that is available to the drainage area.

BMP systems minimize disruption to the hydrologic balance through the use of alternate sediment controls (Western Coal Mining Work Group, 1999c). Case Study 1 predicted that, with BMP system application in the Desert Southwest, approximately 73 acre-feet of water would be available as a result of the receipt of a 10-year, 24-hour precipitation event. By depriving downstream channels of small but relatively frequent flows, channel geometry is not maintained (Doehring, 1985). Unused channels are modified by the processes of mass wasting; caving banks and slope processes that destroy the channels and eliminate their ability to convey flows of sediment and water. In cases where some flow is maintained, a small, "underfit", inner channel is produced. While sedimentation ponds may be capable of achieving the sediment concentration reductions necessary to meet EPA discharge limitations, the net effect of achieving those reductions is often the triggering of large bursts of sediment produced by channel adjustments. When substantial flows return, either due to a high yield storm or due to removal of the sedimentation pond, accelerated erosion and flooding can be expected.

Many western states have long recognized the social and economic importance of their limited surface water and ground water resources and have instituted water rights procedures to prioritize and allocate beneficial usage. However, in order to achieve existing CWA effluent criteria for coal mining operations, regulations and guidelines emphasizing the construction of sedimentation ponds may discourage beneficial usage of water. Regardless of the magnitude of drainage area controlled, the construction and operation of sedimentation ponds reduces the amount of surface runoff available for downstream users. The loss of surface water runoff and ground water recharge due to sedimentation ponds continues to be an issue in water rights negotiations (Western Coal Mining Work Group, 1999a).

### *3.2.3 Sediment Retention*

In arid and semiarid western coal mine regions, large amounts of sediment are readily and naturally transported. Sediment is an important and integral part of these hydrologic systems. In fact, these systems depend upon a continual source and flow of sediment to maintain the existing natural sediment balance.

In order to predict the amount of sediment that will be transported out of a representative model mine in an arid western watershed, the Western Coal Mining Work Group implemented SEDCAD 4.0 (Western Coal Mining Work Group, 1999c). With the implementation of sedimentation ponds to comply with numeric effluent guidelines, SEDCAD 4.0 estimated that 0.0 acre-feet of sediment per year would be transported out of the watershed. With implementation of appropriate alternative sediment control BMPs, SEDCAD 4.0 estimated that an average annual sediment yield of 6.7 acre-feet would be transported out of the watershed, which closely approximates the 8.3 acre-feet per year estimated sediment yield for an undisturbed watershed (see Section 5.1, Case Study 1). The essential containment realized by the sedimentation ponds represents a gross disruption of sediment movement through the fluvial system.

### *3.2.4 Scouring and Seeps*

SMCRA requires operators of coal mines to prevent, to the extent possible, additional contributions of sediment to receiving waters, and to protect the balance of the hydrologic system. Since sediment is an integral part of the arid and semiarid geomorphic and hydrologic system, maintenance of background levels of sediment in mine discharges is crucial to maintaining the hydrologic balance (Water Engineering and Technology, 1986). At times of normal runoff in this region, sedimentation ponds can intercept and detain virtually all flow and waterborne sediment, including both the natural and the mining-generated components (Doehring, 1985). Additionally, clean water that is released from the ponds can accelerate erosion in channel beds in the reach immediately downstream (Williams and Wolman, 1984).

The combination of localized scour (increased erosion caused by sediment-free water) coupled with attenuated flows can cause the incised channel width to decrease within this reach. Riparian and other hydrophytic vegetation are limited in arid and semiarid regions, and fluctuations in water tables fed by surface water runoff can cause these valuable biologic communities to shrink considerably or even disappear.

Another potential impact from the implementation of sedimentation ponds, as the only means to control sediment, is the occurrence of intermittent seeps that have been observed and monitored at several sites since the early 1980s (Western Coal Mining Work Group, 1999a). Intermittent seeps reported at Peabody Western Coal Company's Black Mesa Mine have developed as a result of impounded water interacting with local geologic materials in the vicinity of the sedimentation pond embankments. These seeps are expected to persist intermittently at several pond locations until the ponds are removed and reclaimed. Concerns expressed by local residents resulted in an EPA requirement to study the seeps, report the findings of the study, and develop a plan to mitigate the seeps as part of the Black Mesa NPDES permit. The formation of springs and seeps in the immediate downstream vicinity of sedimentation ponds also can result in a localized proliferation of vegetation that can encroach on channels (Williams and Wolman, 1984).

## 3.3 Sediment Control BMPs

Erosion and sediment controls are used to reduce the amount of soil particles that are carried off of a land area and deposited in receiving water. Soil erosion and sediment control is not a new technology. Many sediment control BMPs already are an integral part of mining and reclamation operations and do not require additional engineering designs or construction. For this reason, implementation can require minimal additional labor and the use of conventional equipment and materials that already are on site and operational. Most BMPs are adaptable to all regions of the country, with the exception of extremely arid regions of the West (Montana DEQ, 1996). In these regions, conventional BMP designs may need to be refined to account for high evaporation rates, and new or modified BMP options should be explored. The USDA Soil

Conservation Service and a number of state and local agencies have been developing and promoting the use of sediment control technologies for years (EPA, 1992).

Design and application of erosion and sedimentation control technology has improved since the passage of SMCRA and since EPA's promulgation of technology-based numerical effluent limits. Extensive monitoring and case studies have been performed on arid and semiarid lands to characterize the nature and extent of erosion occurring within these areas. Computer sedimentation modeling of arid and semiarid fluvial systems has advanced significantly, evolving into site-specific models that are sensitive to the highly variable environmental factors found within the region. Designers and manufacturers of erosion and sedimentation control products have also contributed significantly to the improvement of BMPs. Manufacturers are providing improved and innovative products capable of addressing generic and specific sediment and erosion control problems. Advanced computer prediction models, comprehensive environmental erosion and sediment management practices, and new erosion control materials and equipment form the core of the BMPs that may more appropriately address sedimentation in arid and semiarid coal mining regions.

Using BMP systems designed to address site-specific erosion and sedimentation concerns using current modeling techniques, it is now possible to effectively control erosion and sediment transport, while concurrently minimizing disruption of the fluvial balance. Allowing runoff to "flow naturally" from disturbed and reclaimed areas is environmentally and socially preferable to non-consumptive retention in sedimentation ponds that is accompanied by episodic releases of runoff resulting in sediment imbalances that are potentially disruptive to watershed fluvial morphology.

In summary, BMPs may be either short-term or long-term in their effectiveness. Methods and practices that are capable of harvesting and conserving moisture, limiting soil detachment and erosion, or accomplishing both simultaneously with reasonable economic expenditures find ready acceptance and wide use throughout the mining industry (Western Coal Mining Work Group, 1999a). Many types of erosion and sediment control BMPs and methods are currently used by the coal mining industry within reclaimed areas, serving to reduce the total sediment impoundment volume required to treat runoff to numerical effluent standards. Increased focus on the implemention of site-specific sediment control BMPs serves to address sediment at the source, enhance vegetation growth and stabilize reclaimed lands.

BMPs can be categorized into two descriptive types, either Managerial or Structural. These may vary over the life of the disturbance or reclamation period, depending upon changing site conditions. The characteristics and components of each type of BMP are presented in greater detail in Sections 3.3.1 and 3.3.2.

### *3.3.1 Managerial BMPs*

Managerial sediment control BMPs include project design and planning methods used to protect water quality and minimize erosion and sedimentation. Managerial BMPs are employed prior to, during, and following reclamation of a site. Managerial methods that may be employed at a site are listed in Table 3b.

**Table 3b: Examples of Managerial Sediment and Erosion Control Practices (Western Coal Mining Work Group, 1999a)**

| Managerial Sediment | Implementation Technique |
|---|---|
| Minimizing the Area of Disturbance | Surface disturbances are minimized to that specific area necessary to conduct the mining and reclamation. |
| Appropriate Application | BMPs are judiciously used based on erosion and sedimentation control capabilities, site-specific environmental conditions, and sedimentation predictions. |
| Timely Placement | Structures are placed at the most appropriate time to function properly and effectively during their anticipated use period. |
| Control Sediment at Source | BMPs are implemented at the source of sediment. Terraces, check dams, straw bales, riprap, mulch, silt fences, etc. are implemented to control overland flow, trap sediment in runoff or protect the disturbed land surface from erosion. |
| Contemporaneous Reclamation | After mineral extraction is complete, disturbed areas are reclaimed as rapidly as is practicable and rehabilitated for the designated post-mining land use. |
| Periodic Inspection, Maintenance and Replacement | BMPs are periodically inspected during construction and use. Based on these inspections, maintenance is scheduled and adequately performed. When structures can no longer be reasonably maintained, they are replaced if necessary. When BMP structures are no longer needed, they are removed, if necessary, and the disturbed area reclaimed. Most BMPs are installed as integral components of the surface drainage system and their removal is not needed. |

### *3.3.2 Structural BMPs*

Structural BMPs are the physical structures, methods, practices, and products implemented and used to achieve erosion and sedimentation control. These BMPs are combined with managerial practices and monitoring plans to form complete BMP systems for a given site. Structural sediment control BMPs primarily include regrading, revegetation, sediment trapping, and control of surface runoff. Examples of common structural sediment control BMPs are listed in Table 3c. EPA recognizes that Table 3c is not inclusive of all sediment control BMPs that are appropriate for use in arid and semiarid regions. Numerous additional BMPs and BMP combinations currently exist and are being used effectively.

**Table 3c: Examples of Structural Best Management Practices (Western Coal Mining Work Group, 1999a, Carlson, 1995, Bonine, 1995, Toy and Foster, 1998, U.S. Mining and Reclamation Council of America, 1985)**

| BMP | Sediment Control Characteristics And Design Techniques |
|---|---|
| Straw Bales | Inhibit surface runoff and stop the movement of sediment. Bales are used across medium slopes or at the toes of steep slopes. |
| Terraces or Benches | Reduce slope lengths and water velocities and increase infiltration. Constructed as wide (10'-20') horizontal, level or slightly reverse sloping steps in intervals down the slope on or near contours. |
| Deep Ripping | Breaks compacted layers, heavy clays, and soil-minesoil interfaces. Increases infiltration and reduces flow velocities. Ripping loosens and mixes subsoil and allows root penetration and subsurface water storage. |
| Contour Berms | Control or divert surface runoff flow. Care must be taken to assure a level top surface with no low spots where breaching could occur. Berm height varies from one to three feet. Berms that will be in existence for longer than one year are vegetated to reduce erosion. |
| Diversion Channels | Convey runoff from points of concentration across, through, along, and around areas to be protected. Designed for peak flows based upon a 10-year, 24-hour storm event. Typically two feet deep with a run-to-rise ration of 3:1. Those in existence for longer than one year are vegetated to reduce erosion. |
| Check Dams | Stabilize channel grades and control channel head cutting. Reduce or prevent excessive erosion by reducing velocities in diversions, conveyances and sedimentation pond inlets or by providing partial channel sections or structures that can withstand high flow velocities. Dam height is dictated by flow amount, channel slope, and available cross sectional area. Sized to pass 10-year, 24-hour runoff event. |
| Interceptor Ditch - Slope Drain (Contour Ditch) | Ditches are placed horizontally at vertical intervals on long slopes to reduce the effective slope length, slow runoff, reduce erosion and enhance sediment deposition. They are generally 1.5 feet deep with a run-to-rise ration of 2:1. Ditches are spaced approximately 50 feet apart horizontally. |
| Mulch | Temporary soil stabilization. Used to increase infiltration, retain water, add surface roughness, decrease runoff, protect soil surface from erosive action of raindrops, and to enhance seedbed for vegetative growth. When used together with seeding or planting, mulching can aid in plant growth by holding the seeds, fertilizers, and topsoil in place. Helps to retain moisture and insulate against extreme temperatures. In general, higher mulch application rates (lbs/acre) are needed for western regions. |
| Mulch Crimping | Increases the effectiveness of mulch against surface erosion by water and wind. It is accomplished by tacking mulch materials into the soil surface using blunt or notched disks that are forced into the soil. |
| Geotextiles | Geotextiles, when used alone, can be used as matting to stabilize runoff flow. Geotextile matting also can be used on recently planted slopes to protect seedlings until they become established or as a separator between riprap and soil. |

| BMP | Sediment Control Characteristics And Design Techniques |
|---|---|
| Roughened Surface - Control Discing | Increases infiltration. Surface roughening is commonly accomplished through the use of agricultural techniques including discing, plowing, contour furrowing, and land imprinting. |
| Pitting | A mechanical treatment measure which creates small, basin like depressions that increase surface water revegetation potential of a site. Pitting as a water conservation and erosion control measure is used on mined lands before seeding and planting. The method has been used mainly in arid or semiarid regions where the water conservancy methods are most critical. |
| Sediment Traps | Provide small storage or detention areas without special inlet or outlet controls. Constructed by excavation, or by creating an impoundment with logs, silt fence or brush barrier/filter cloth as a low head dam. |
| Contour Plowing | Prevents rill formation. Furrows formed by contour plowing also add roughness and enhance infiltration. |
| Complex Slope | Slopes graded with three segments: upper convex, middle straight, lower concave. Straight slopes are minimized and concave slope is maximized to reduce erosion and promote deposition on the lower slope segment. |
| Drainage to Pit | Runoff from disturbed areas drains either directly to or is diverted to the pit. This water evaporates or is pumped to holding ponds. Holding pond water is discharged in accordance with NPDES requirements. |
| Cover Crop | Broadcast or drill seeded. Establishes quick live cover & root system. Stubble acts as surface roughness during winter. |
| Regrading | Regrading to approximate original contour or other acceptable slope gradients and configurations can substantially reduce soil loss rates. Although the construction of complex or concave hill slope profiles offer grading challenges, these shapes can substantially reduce soil loss rates. |
| Livestock Grazing | Controlled livestock grazing can have positive sediment control impacts on reclaimed areas, such as increasing vegetation cover and production, creating surface roughening, promoting soil formation, and increasing soil microbial populations, all of which serve to control erosion and sedimentation. It is important to have established vegetative cover prior to allowing grazing on reclaimed land. |
| Irrigation | If there is not enough rainfall on the area for establishing vegetation, the area can be irrigated. |
| Landscape Configuration | Establishes reclaimed topography that is stable with surrounding terrain and climate. Configuration measures include shorter slopes, complex slopes, and proper drainage profiles. |
| Revegetation | Adds soil stability and surface roughness, reduces rainfall erosion, and physically secures soil making it less erosive. |
| Toe Drain Ditches | Store or divert slope runoff. These channels are open, of any cross sectional shape and are constructed at the toe of exposed slope surfaces. |

### *3.3.3 BMP Implementation*

Selection of sediment control BMPs for mining or reclamation activities should be based on site-specific conditions. The BMP plan should be designed to: minimize the amount of disturbed soil, control runoff flowing across a site, remove excess sediment from onsite runoff before it leaves the site, and meet or exceed local or state requirements for sediment and erosion control plans. In most situations, a combination of BMPs is necessary to adequately control sediment and erosion. Moreover, these BMPs must be properly designed, implemented and maintained in order to be effective. Implementation of managerial practices and structural sediment control BMPs, either in addition or as an alternative to sedimentation ponds, should be expected to:

- Maintain adequate "natural sediment loading" to avoid disruption of the fluvial system, while preventing impacts to environmental and biologic resources in watersheds affected by mining;
- Minimize reductions in downstream runoff;
- Reduce unnecessary additional disturbance of surface acreage; and
- Restore or improve riparian and natural vegetative species.

Appropriate alternative sediment control BMPs can be designed and implemented using site-specific design evaluations of the various disturbance activities anticipated over the life of the mining or reclamation operation. BMPs may be used singly or in combination to effectively control and minimize erosion and sedimentation from disturbed areas.

BMP plans should consider the background environmental conditions (i.e., size of site, soil types, drainage pattern, rainfall data, receiving channels, and land use) to establish reasonable and acceptable implementation and monitoring design criteria. The design should include modeling of disturbance phases to determine the control and treatment practices and methods to be used to ensure compliance with the site-specific performance-based standards during the various disturbance and reclamation phases. BMP designs should demonstrate that erosion will be controlled, deepening or enlargement of stream channels will be prevented, disturbance of the hydrologic balance will be minimal, and additional contributions of sediment of stream flow and runoff outside the permit area will be prevented to the greatest extent possible. BMP design, construction, implementation, and monitoring represent the complete BMP system for a given location.

The key to the effective planning and implementation of a BMP system is deployment flexibility. For a given situation, there may be several BMP combinations that will adequately control erosion and sedimentation. The type of BMP that is most effective may also change through time. For example, during the early stages of establishing vegetation on non-process areas, livestock grazing represents a potentially disruptive land use activity. However, once the vegetation is firmly established, livestock grazing can act as an effective BMP. The operational preferences of mining companies can result in the design and use of a variety of different combinations of sediment control practices for essentially similar areas. The critical goal that must be realized is the adequate control of surface erosion and retention of sediment in order to meet the site's water quality requirements. The primary purpose of sediment control BMPs is to control sediment at the source and to minimize erosion caused by wind and water. A sediment control plan should demonstrate that all exposed or disturbed areas are stabilized to the greatest extent possible.

Sediment control BMPs can be categorized according to function as follows: Topographic, Slope Erosion, Flow Structures, Soil Conservation, and Vegetation. BMPs that fall within these categories may be universal or limited in their application. For example, reconstructed drainage channels usually are limited to use within low-lying reclaimed areas, while permanent vegetation typically is established throughout a reclaimed landscape. Appropriate sediment control BMPs are designed and implemented using site-specific evaluations of the various activities anticipated during mining or reclamation operations.

### 3.3.3.1 Topographic BMPs

In order to prevent unnatural sedimentation, mined land surface areas should be reclaimed to a grade necessary to control surface water runoff and promote appropriate drainage and stability. Terrace and bench-type grading can prevent slides and sedimentation while promoting slope stability. Topographic BMPs include:

- Planning post-mining topography using modeling to mimic approximate original contour or pre-mining natural, background erosion and sedimentation yields;
- Designing and implementing a BMP plan that will approximate natural drainage as closely as possible;
- Choosing sediment control structures according to review of existing topography, flow direction and volume, outlet location, and feasibility of construction;
- Backfilling and grading to approximate original topography or other acceptable slope gradients and configurations. Blending disturbed areas into the surrounding terrain; and
- Eliminating unstable areas to the greatest extent possible.

### 3.3.3.2 Slope Erosion

BMPs that control slope erosion are implemented to stabilize and protect slopes against surface erosion. Slope surfaces should be mulched, vegetated or otherwise stabilized to minimize sediment movement, and, on a site-specific basis, to address particular erosion problem spots according to need. Construction of terraces, benches, and other grading or drainage control measures can be utilized to prevent erosion and ensure slope stability. These structures should be designed to be non-erodible and to carry short-term, periodic flows at non-erosive velocities. These BMPs often help stabilize steeply sloped areas until vegetation can be established. BMPs that serve to control erosion and sedimentation from slopes include:

- Limiting slope length according to modeling prediction of surface runoff sediment yield;

- Creating slope shapes which promote stability through protective surface configurations (concave vs. convex, simple vs. complex);
- Providing non-erosive mulches or surface cover materials (e.g., durable rock fills that limit erosion through adequate surface protection); and
- Segmentation of slopes through construction of terraces or benches to limit slope length and provide protected drainage.

#### 3.3.3.3 Flow Structures

Hydrologic flow structures are implemented to ensure that additional contributions of sediment to stream flow and to runoff outside the permit area are prevented to the greatest extent possible. These BMPs are implemented to direct runoff away from exposed or unstable surface areas, to control runoff volume and velocity, and to provide water for establishment of vegetative cover. These structures should be inspected regularly, compacted according to applicable standards, and maintained properly to ensure maximum effectiveness. BMPs that utilize flow structures include:

- Implementing diversions, reclaimed channels, drains, terrace drains, down-drains, and ditches capable of conveying surface water runoff from designated worst-case storm events and worst-case watershed disturbance conditions around, through or from the disturbed/reclaimed area;
- Implementing flow structures in a manner that reduces runoff flow velocity and thus reduces loosening or removal of soil particles; and
- Designing flow structures with adequate sizing, configuration and protective linings to provide stable watercourses for anticipated flow volumes and velocities.

#### 3.3.3.4 Soil Conservation

BMPs that are implemented to conserve soil tend to protect exposed surfaces against the erosive effects of wind and water by manipulating the soil surface or providing surface cover amendments. A sediment control BMP plan should demonstrate that all exposed or disturbed areas are stabilized to the greatest extent possible, as quickly as possible following disturbance. Surface erosion protection practices and materials include:

- Mulching with organic or inorganic materials or applying geotextile fabrics;
- Preserving existing vegetation;
- Establishing quick-growing cover crops with annual or perennial plant species; and
- Roughening exposed surfaces. Surface roughening is commonly accomplished through the use of agricultural techniques including discing, plowing, and contour furrowing.

#### 3.3.3.5 Vegetation

Land in arid and semiarid climates tends to have relatively low vegetation cover and productivity, particularly where annual rainfall is less than 9 inches per year. Total vegetation cover values frequently fall within the range of 5 to 20 percent. Yearly vegetation production tends to be low, with most reclaimed areas producing between 500 to 1,000 pounds per acre annually (Western Coal Mining Work Group, 1999a).

Preserving existing vegetation or vegetating disturbed soil as soon as possible after surface disturbance is the most effective way to control erosion (U.S. EPA, 1992). A vegetative cover reduces erosion potential by: (1) shielding the surface from the direct erosive impact of raindrops, (2) reducing sediment runoff to downstream areas, (3) filtering sediment, (4) improving the soil's water storage capacity, (5) slowing runoff and allowing sediment to drop out or deposit, and (6) physically holding the soil in place.

Establishment of vegetation can be a short-term (temporary) or long-term (permanent) method for controlling erosion and sedimentation. Plant species are selected based upon land use, growth conditions, and environmental requirements. Temporary seeding should take place as soon as practicable after the most recent land disturbing activity. In arid and semiarid regions where the climate prevents fast growth, temporary seeding may not be effective (U.S.EPA, 1992). In these regions, mulching may be more appropriate for short-term stabilization.

Common goals for permanent vegetation include the establishment of adequate cover, production, and diversity to support designated post-mining land use(s), and to protect the soil from excessive surface erosion. Proper seedbed preparation, the use of high-quality seeds, and the application of mulch may be necessary for effective erosion control. In arid and semiarid regions, irrigation and the addition of topsoil or other soil amendments may be required to make conditions more suitable for plant growth. Although the use of native species is recommended, both non-native and native plant species may be used for routine and specialized seeding and transplanting programs. Bioengineering or specialized plantings may be used singly or in combination with hard structures to achieve erosion control and protect and enhance the effective life of critical erosion and sedimentation control structures or features.

Seed mixtures are an integral component of a BMP reclamation plan and are an important component in vegetative success. A diverse seed mixture, coupled with appropriate water management, accelerates early plant community development and diversity. Mixtures and application rates dramatically influence vegetation germination, establishment and development.

Land use can have a dramatic effect on a reclaimed area's vegetation characteristics. Reclamation land use in the arid and semiarid western United States is primarily rangeland with livestock grazing normally a part of the post-mining land use. Controlled grazing can be used effectively to promote vegetation growth and development, soil stability and surface water hydrology. Livestock grazing has been successfully used as part of BMP systems to increase vegetation density on most western coal mine non-process areas.

#### 3.3.3.6 Geochemistry

The geochemistry of the western arid and semiarid coal regions, which is generally alkaline, differs from that of the eastern coal regions. Western alkaline coal regions, unlike eastern regions, contain large quantities of sandstone and limestone that contain high levels of calcium and carbonate minerals (e.g., calcite, dolomite). These minerals inhibit $H^+$ formation from pyrite via the following equation (Hornberger, 1981; Williams, 1982; Perry and Brady, 1995):

$$FeS_2 + 4\ CaCO_3 + 3.75\ O_2 + 3.5\ H_2O \rightarrow Fe(OH)_3 + 2\ SO_4^{2-} + 4\ Ca^{2+} + 4\ HCO_3^-$$

Dissolved carbonate minerals also promote precipitation of dissolved iron and other metals ions to further neutralize acidity. Studies have shown that a 3% (or greater) concentration of carbonate minerals will produce alkaline mine drainage (*Coal Mine Drainage Prediction and Pollution Prevention in Pennsylvania*, 1999). The net alkalinity of drainage from these coal regions indicates high concentrations of carbonate that will counter potential acidity. As a result, the production of acid mine drainage is much less typical due to the inherent buffering capacity.

In natural undisturbed conditions, surface water samples in the arid/semiarid western United States can register values for total iron as high as 40,000 mg/L (or 4%), due to the sediment that is collected as part of the water sample. The primary mineral responsible for the high total iron readings is often magnetite, which is often visible on the floor of arroyos.

In addition, in the western coal regions there is a low occurrence of pyrite which, along with dissolved iron, is the common culprit of acid mine drainage generation. Instead, iron often occurs in the form of magnetite ($Fe_3O_4$), a solid, inert iron oxide that has no acid-forming potential. The following data from a USGS website support the commenter's assertion that there is comparatively less iron (average of almost 1:3) and pyritic sulfur (average of over 1:5) in western coal versus eastern coal (Table 3d):

**Table 3d: Summary of Coal Quality Data in Western and Eastern Coal Regions**

| | Western Coal Region[1] | | | Eastern Coal Region[2] | | |
|---|---|---|---|---|---|---|
| | **N** | **Range** | **Average** | **N** | **Range** | **Average** |
| **Total Iron (mg/L)** | 1258 | 110 - 52,000 | 5652 | 4511 | 72 - 120,000 | 15,082 |
| **Sulfate (%)** | 1045 | 0 - 0.69 | 0.03 | 3623 | 0 - 25.54 | 0.07 |
| **Pyritic Sulfur (%)** | 1045 | 0 - 4.5 | 0.25 | 3905 | 0 - 12.1 | 1.32 |
| **Total Sulfur (mg/L)** | 1191 | 15 - 31,000 | 3722 | 4401 | 4 - 20,000 | 1072 |

Data from http://energy.er.usgs.gov/coalqual.htm : National Coal Resources Data System, U.S. Coal Quality Database.
[1]Data from the following States were considered under the Western Coal Region: AZ, CO, NM, WY
[2]Data from the following States were considered under the Eastern Coal Region: AL, KY, MD, OH, PA, TN, VA, WV

Of the forms of iron that can exist in coal mine discharges, only pyrite and dissolved iron have acid-forming potential at pH $\geq$6. Dissolved iron contained in coal mine drainage can come from multiple sources, one of which is pyrite. The series of reactions below characterize pyrite oxidation and the resulting acid formation. As can be seen, dissolved iron ($Fe^{2+}$, $Fe^{3+}$) is an intermediate product of acid formation from pyrite.

1) $FeS_2$ (pyrite)(s) + 3.75 $O_2$ + 3.5 $H_20$ = $Fe^{2+}$ + 2 $SO_4^{2-}$ + 2 $H^+$
2) $Fe^{2+}$ + 0.25 $O_2$ + $H^+$ = $Fe^{3+}$ + 5 $H_2O$
3) $FeS_2$ (pyrite)(s) + 14 $Fe^{3+}$ + 8 $H_2O$ = 15 $Fe^{2+}$ + 2 $SO_4^{2-}$ + 16 $H^+$
4) $Fe^{3+}$ + 3 $H_2O$ = $Fe(OH)_3$(s) + 3 $H^+$

Studies have shown that, in most coal mine drainage, an abundance of dissolved iron indicates $H^+$ formation from pyrite oxidation (Rose and Cravotta, 1999). Therefore, even if pyrite is present (which is unlikely in the western coal regions), the effect of its presence will not escape detection so long as dissolved iron is measured. Other forms of iron, such as iron hydroxide ($Fe(OH)_3$(s)) and magnetite ($Fe_3O_4$(s)), are insoluble and unreactive at pH $\geq$ 6. In fact, encouraging magnetite precipitation is being investigated for use in treatment of acid mine drainage (Morgan, 2001).

EPA has established the applicability of the Western Alkaline Coal Mining Subcategory as follows: "This subpart applies to drainage at western coal mining operations from non-process areas, brushing and grubbing areas, topsoil stockpiling areas, and regraded areas where the discharge, before any treatment, meets all the following requirements: pH is equal to or greater than 6, dissolved iron concentration is less than 10 mg/L, and net alkalinity is greater than zero." This applicability is consistent with the definitions of both acid and alkaline mine drainage, and with EPA recognition that net alkalinity or acidity is a the defining characteristic of acid mine drainage in terms of the potential to form more acidity.

## 3.4 Prediction Models for BMP Design and Implementation

The major factors affecting soil erosion are soil characteristics, climate, rainfall intensity and duration, vegetation or other surface cover, and topography. Understanding the factors that affect erosion makes it possible to predict the extent and consequences of onsite erosion (U.S. EPA, 1992). Although an estimate of sediment erosion and deposition can be derived over time using water samples or sediment accumulation markers, this method of erosion prediction can be time consuming and labor intensive. Prior to implementation of sediment control BMPs, it is important to determine both the quantity of sedimentation and the sedimentation patterns that can be expected. Sites must be assessed to determine pre-mining drainage patterns and topography, to quantify effects of storm runoff and the yield of coarse- and fine-grained sediment, and to determine morphologic evolution of streams, washes, and arroyos.

Although an estimate of sediment erosion and deposition can be derived over time using water samples or sediment accumulation markers, these methods of erosion prediction are time consuming and often labor intensive. The collection of sufficient soil-loss data from natural rainfall events on erosion plots to permit confidence in the results of statistical analyses has proven to be a long-term, expensive, and inefficient undertaking (Toy, 1998). Sediment transport can be predicted with reasonable accuracy using computer models developed for this purpose during the last 20 years.

Computer models have been developed to assess and predict erosion, soil loss, and sediment yields from undisturbed lands experiencing overland flow, from lands undergoing disturbances, and from newly established or reclaimed lands. Computer models are commonly used to evaluate watershed response and assess impacts of land use and are capable of determining the effectiveness of BMPs on erosion control and sediment production prior to field use. These models are particularly valuable in arid and semiarid areas because the infrequency of precipitation discourages compilation of data from instrumented watersheds. When calibrated, the models provide a means for comparing sediment loss under undisturbed (premine) and reclaimed mine land conditions (Peterson, 1995). Examples of soil loss prediction models include:

- SEDCAD 4.0
- RUSLE
- EASI
- SEDIMOT II
- MULTSED

The efficiency and accuracy of these models has improved dramatically as extensive environmental databases and product specifications have been developed. A great deal of study has been performed regarding mined land and new erosion and sedimentation control and treatment products, to develop and verify these modeling programs. Most importantly, the models provide a constant base from which to evaluate pre-mining and post-mining sediment delivery (Peterson, 1995). Computer simulations allow mine operators to determine which combination of managerial and/or structural BMPs will be most effective at controlling sediment and erosion at a specific mining or reclamation site.

### *3.4.1 Revised Universal Soil Loss Equation (RUSLE)*

The Universal Soil Loss Equation (USLE) developed in 1961, was designed to predict average annual soil loss caused by sheet and rill erosion. The USLE can estimate long-term annual soil loss and guide conservationists on proper cropping, management, and conservation practices, but it can not be applied to a specific year or a specific storm event. USLE was modified as the Modified Universal Soil Loss Equation (MUSLE) to replace USLE's rainfall factor with a runoff factor. The MUSLE model assumes that sediment yield is related to peak discharge and runoff volume.

The Revised Universal Soil Loss Equation (RUSLE), based extensively on the USLE model and its data, was developed to estimate average annual soil loss in larger, steeply sloped areas and can accommodate undisturbed soil, spoil, and soil-substitute material, percent cover, random surface roughness, mulches, vegetation types, mechanical equipment effects on soil roughness, hill-slope shape, and surface manipulation. RUSLE is applicable to sheet and rill detachment only, and does not estimate gully or stream-channel erosion or compute deposition.

RUSLE is based on a set of equations that estimate annual soil loss (soil removed from the hillslope or hillslope segment). It was derived from the theory of erosion processes, more than 10,000 plot-years of data from natural rainfall plots, and numerous rainfall-simulation plots. RUSLE retains the structure of USLE (Pennsylvania Department of Environmental Protection, 1999, Renard, 1997) and takes the form of the following equation (Toy, 1998).

$$\mathbf{A = RKLSCP}$$

<u>Where</u>:

A = Computed Soil Loss (Annual Soil Loss as tons/acre/year)

R = Climatic Erosivity or Rainfall erosion index - a measure of the erosive force and intensity of a specific rainfall or the normal yearly rainfall for specific climatic regions

K = Soil Erodibility Factor - Ability of soils to resist erosive energy of rain. A measure of the erosion potential for a specific soil type based on inherent physical properties (particle size, organic matter, aggregate stability, permeability). Soils with a K value of 0.17 or less are considered slightly erodible, and those with a K value of 0.45 or higher are highly erodible. Soils in disturbed areas can be more easily eroded regardless of the listed K value for the soil type because the structure has been changed.

LS = Steepness Factor - Combination factor for slope length and gradient

C = Cover and Management Factor - Type of vegetation and cover. The ratio of soil loss from a field with specific cropping relative to that from the fallow condition on which the factor K is evaluated.

P = Support Practice - Erosion control practice factor, the ratio of soil loss under specified management practices.

### *3.4.2 SEDCAD*

SEDCAD is a comprehensive model that enables the user to evaluate the performance of erosion and sediment controls. SEDCAD calculates the amount of runoff and sediment generated in response to a given precipitation event for specific soil and vegetative cover conditions, analyzes the effectiveness of sediment/erosion control structures in meeting effluent standards, and allows the design of cost effective sediment erosion control structures. SEDCAD is widely used throughout the mining industry and is the program used by the OSMRE to review mine permits, and to design and evaluate structure performance in OSMRE's Abandoned Mine Land Program.

SEDCAD is a hydrology and sedimentology routing model used to simulate peak flows, drainage volumes, and sediment yields from undisturbed and disturbed/reclaimed watersheds. Hydrograph development and peak flow determination are based on user inputs of a design storm (e.g., rainfall amount and duration and selection of a rainfall distribution). Hydrographs are developed on a subwatershed basis with the input area, time of concentration, Natural Resources
Conservation Service (NRCS) curve number, and selection of one of three dimensionless double triangle unit hydrographs. Routing of hydrographs is accomplished by Muskingum's method (Warner and Schwab, 1998).

The sediment yield and concentrations of TSS and SS are also determined on a subwatershed basis. SEDCAD uses a subroutine that implements a method similar to RUSLE to determine average annual sediment yield. SEDCAD sedimentology input values may be taken directly from RUSLE results, allowing the two models to work in tandem. Sediment routing is determined in conjunction with runoff hydrograph routing, and considers the eroded particle size distributions of the soils exposed to rainfall and runoff. An example of combining RUSLE and SEDCAD computer models to determine background sediment yield and predict the effects of sediment controls is presented in Section 5, Case Study 1.

### *3.4.3 SEDIMOT II*

SEDIMOT II considers a number of field parameters (sediment type and concentration, vegetation type, slope and length of filters) that affect sediment transport and deposition through filtering materials or vegetation. SEDIMOT II is capable of evaluating the hydraulic and sediment response of a watershed as well as the effectiveness of detention ponds, grass filters, and check dams (Wilson, 1984). Flow is described by the continuity equation and by steady-state infiltration (i.e., flow decreases linearly from upstream to downstream in the filter). SEDIMOT II is based on the hydraulics of flow and the transport and deposition profiles of sediment in laboratory conditions. The model does not handle time dependent infiltration or changes in flow resulting from sediment deposition during a storm event.

The user of the model divides the drainage basin into subwatersheds of relatively uniform land use. A hydrograph, sediment graph, and particle size distribution are determined for each subwatershed, routed downstream, and then combined to form a composite hydrograph, sediment graph, and particle size distribution. In the hydrologic component of SEDIMOT II, the Soil Conservation Service (SCS) curve number method is used to determine rainfall excess, the unit hydrograph theory is used to calculate a runoff hydrograph, and the Muskingum procedure is used for channel routing. An example of combining SEDIMOT II and SEDCAD computer models to determine background sediment yield and design sediment control plans is presented in Section 5, Case Study 2.

### *3.4.4 HEC-6*

The HEC-6, Scour and Deposition in Rivers and Reservoirs model was developed by the United States Army Corp of Engineers (U.S. Army Corp of Engineers, 1999). It is a one-dimensional, movable boundary, open channel flow, numerical model. HEC-6 was designed to simulate and predict changes in river profiles resulting from scour and/or deposition over moderate time periods (typically years, although applications to single flood events are possible). HEC-6 calculates water surface and sediment bed surface profiles by computing the interaction between sediment material in the stream bed and the flowing water-sediment mixture.

HEC-6 simulates the capability of a stream to transport sediment, given the yield from upstream sources. Prediction of sediment behavior requires that the interactions between the flow hydraulics, sediment transport, channel roughness, and related changes in boundary geometry be considered. HEC-6 is designed to incorporate these interactions into the simulation. Channel bed elevation changes resulting from net scour or net aggradation are reported after a series of uniform discharges of finite duration have been simulated. In this way, a continuous hydrograph is simulated by a histogram. HEC-6 can be used to predict the impact of land manipulation or construction on the river hydraulics, sediment transport rates, and channel geometry.

### *3.4.5 MULTSED*

The Watershed and Sediment Runoff Simulation Model for Multiple Watersheds (MULTSED) simulates the sedimentation processes of detachment, transport, and deposition. MULTSED was developed at Colorado State University with support from EPA and the USDA-Forest Service. In a 1990 comparison of MULTSED, ANSWERS, KINEROS, PRMS, and SEDIMOT II, MULTSED was found to be the best overall model for semiarid lands (WET, 1990).

One of MULTSED's strengths is its simulation of channel processes, which often have a greater impact than hillside processes in a semiarid environment. MULTSED represents the watershed as a cascade of planes and channels and simulates channel infiltration, erosion and deposition in addition to calculating sediment transport by size fraction. Rainfall is input independently for each plane, and runoff is simulated as a kinematic wave with laminar characteristics. Channel runoff is simulated as a kinematic wave with finite difference.